C introduction

Dynamic memory management

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Runtime conditions

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Static C arrays are great if you already know at *compile time* how many elements you will need later at *runtime*.

Seriously, how often is this the case?

Never. Unless your program does not take *any* user input, you cannot determine how much data you will have to store.

This is where dynamic memory management comes into play.

Explicit allocation

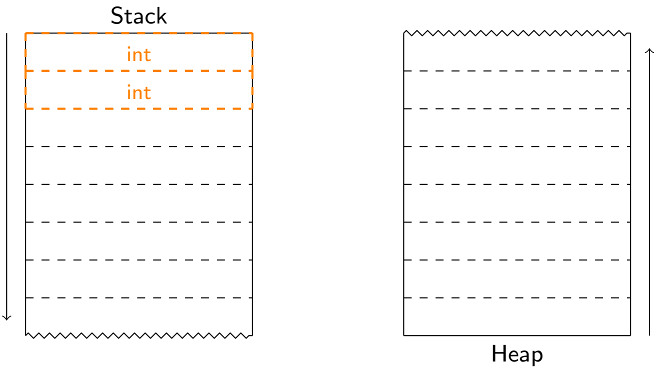
All the variables and arrays you have used so far were placed in memory automatically. In dynamic memory management, you have to *allocate* parts memory to identifiers on your own.

There are four functions in the standard library that do almost all the work for you:

- *malloc()*: Allocate a block of memory
- *calloc()*: Allocate a block of memory and initialize it
- *realloc()*: Alter the size of a block of memory
- *free()*: Release a block of memory

They are declared in *stdlib.h*.

A closer look at memory



All local variables of functions are placed at the *stack*.
It grows and shrinks as variables are declared and functions return.

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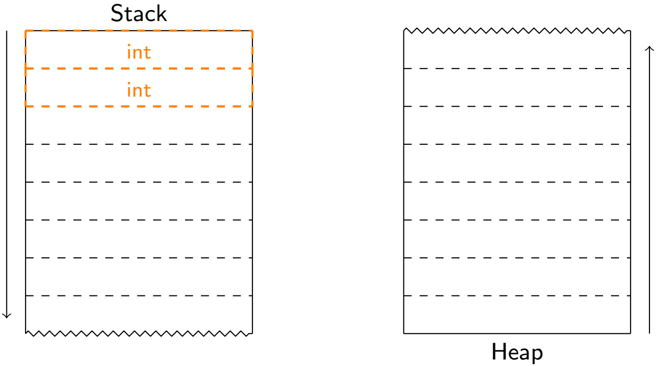

Dynamical memory is allocated on the *heap*.
The example shows a function with two local *int* variables.

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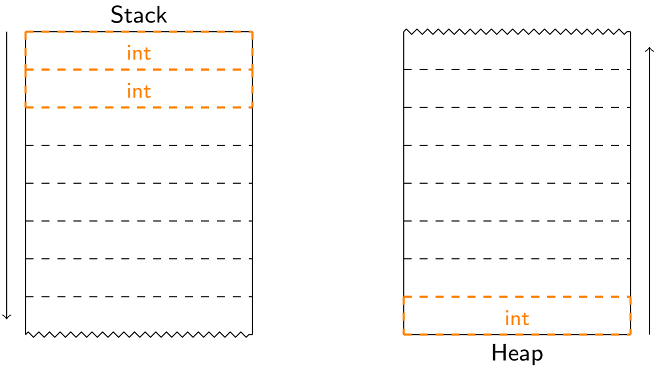
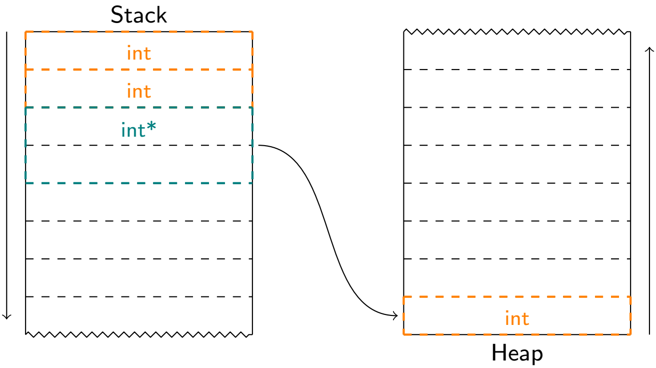



```
malloc(sizeof(int));
```

Reserves exactly the amount of memory an *int* variable takes.

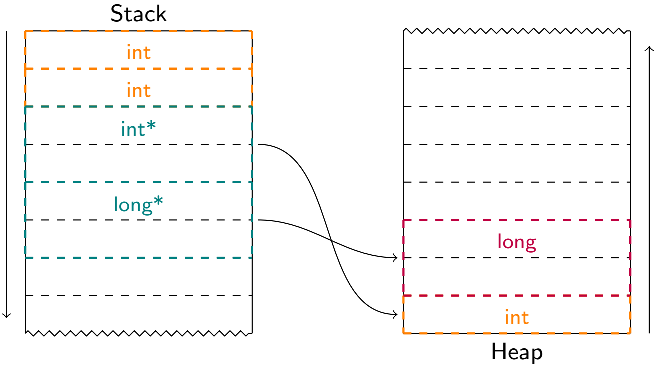
A closer look at memory




```
int *new_block = malloc(sizeof(int));
```

The adress of that memory block is stored in an *int* pointer.

A closer look at memory



malloc() just needs to know the size of the block it reserves.
Let's allocate a *long* variable as well.

malloc() in detail

The function declaration might be a little bit confusing:

```
void *malloc(size_t size);
```

- *size_t* is an **unsigned integer** type.
  Any positive integer number (e.g. an *int* > 0) will do the job.
- *size* is the size of the reserved block in **bytes**.
  If you want to use that block *seriously*, pass the size of an actual type (e.g. *sizeof(int)*).
- A *void* pointer is returned since *malloc()* does not know how you want to use the reserved block. By assigning it to a regular pointer variable it is automatically converted to that type.

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```
int *block = malloc((sizeof(int));
```

has the same result as

```
int *block = (int*) malloc((sizeof(int));
```

while the second one contains a reduntant *cast* and if you want to change the type of *block* later, you will have to hit more keys. Consider:

```
int *block = malloc(sizeof *block); /* for lazy people */
```

Cast or don't cast?

Confused?

Cast or don't cast?

Confused?

Forget about type casts.

Tidying up

Unlike normally declared variables, dynamically allocated storage is not automatically released when the function returns.

```
void foo() {
    int *bar = malloc(sizeof(int));
}
```

With the pointer *bar* being removed from the stack, we havo no reference on its allocated memory and those four bytes are blocked forever!

```
free(void *ptr);
```

Pass any pointer to previously allocated memory to *free()* and it gets realeased. If you pass pointers on other things, undefined behaviour occurs (most likely program crashes).

Reserving large junks

To get a dynamic array of a certain *type* and *length*, you have to

- Pass the block size $length * sizeof(type)$ to *malloc()*
- Assign the return value to a pointer to *type*

int array with 42 elements:

```
int *field = malloc(42 * sizeof(int));
```

Since the size of your dynamically allocated array is unknown at compile time, you cannot use *sizeof* to get its length. Save it in its own variable!

With the help of pointer arithmetic, you can use the dynamic array like a "normal" one.

The fancy alternative

```
void *calloc(size_t nmemb, size_t size);
```

- Allocates a block of *nmemb* $*$ *size* bytes, where *nmemb* is supposed to be the array's length and *size* the size its type.
- The whole block is filled with *0*s

```
int field_length = 42;
int *field = malloc(field_length * sizeof(int));
for (int i = 0; i < field_length; i++)
    field[i] = 0;
```

↓ Feel the difference ↓

```
int field_length = 42;
int *field = calloc(field_length, sizeof(int));
```

Resizing arrays

Now we come to the point that motivated us to use dynamic arrays:

```
void *realloc(void *ptr, size_t size);
```

- *ptr* is a pointer to a dynamically allocated memory block
- *size* is the wanted new size of the memory block
- The return value is a pointer to the resized block

Note that the new *size* can be greater or smaller than the old one!

- If it's smaller, you may lose some data at the end of the block
- If it's greater, the block may be at a different location in the memory
  $\rightarrow$ *ptr* is freed then, also the additional bytes are not initialized

Clean up your code

Passing arrays between functions can be complicated if you store the pointer and the length seperataly.

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Do you remember a way to keep different things together?

```
struct int_array {
    int *field;
    int length;
}
```

This allows you to use the *struct int_array* as a single argument or return value. Even better: pass a pointer on that structure.

Strings from pointers to *char*

By handling strings as dynamic *char* arrays you can alter their size which is needed for many operations on them.

- *strlen()* returns the actual length of a string (up to '\0' character)
- *strncpy()* copies a string into a dynamically allocated block

```
char conststr[] = "Hello";                /* not of much use */
int bufsize = strlen(conststr) + 1;       /* add '\0' char */
char *str = calloc(bufsize, sizeof(char));
str = strncpy(str, conststr, bufsize); /* ready to go */
```

These functions and others are declared in *string.h*.

```
$ man string.h
```

String concatenation

strncat() concatenates two strings. Have a closer look at it:

```
$ man 3 strncat
```

- Write a program that reads a series of strings from the user input and concatenates them.
- Each string is put at the front so that the result is in reversed order.

- **Experts**: At the end, let the user enter one last string. Check, if that one occures in the string you have put together.

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  - Hint: *strstr()* may be an option.

Vector operations

- Write a program that takes two vectors as input and prints their sum.
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  - Hint: A 2D dynamic array is a dynamic array of pointers. Each of those pointers has its own dynamic array allocated to it.
  - Hint: You need a lot more conventions!

Hangman

Write a simple hangman game! Everytime the player is wrong, add a new part to the gallows / the hanging man and print it to the terminal:

```
      ______
      |/   o
      |   ^W^
      |   / \         word:  game  o_e_
      |               wrong:  hfnwitc
    ______
   /      \
  /        \
==================
```

Experts: Have a list of possible words in the source code and let the program randomly choose one at the start.

Hint: *strncmp()* compares two strings.